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**A Description of the Mode
Select Beacon System
(Mode S) and its Associated
Benefits to the National
Airspace System (NAS)**

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16. Abstract <p>This report provides a historical perspective and technical description to clarify the background and benefits of the mode select beacon system (Mode S). First, a brief synopsis of the development of the Mode S surveillance function is given in Section 2.0. Section 3.0 provides an overview of the operation of both ATCRBS and Mode S systems to highlight their operational differences. Section 4.0 discusses benefits which will be realized solely as a consequence of Mode S ground sensor installation. Section 5.0 describes how Mode S ground sensor installations provide immunity to synchronous garble and other ATCRBS deficiencies, and describes the advantages realized as a result of near-universal Mode S transponder equipage. The Mode S data link function is described in Section 6.0.</p> <p>This report describes the operation of the Mode S subsystem and identifies benefits that the Mode S system provides to the National Airspace System (NAS) for surveillance and data link operations. These benefits include a reduction in asynchronous interference, reduced sensitivity to synchronous garble, and more accurate and reliable surveillance, and support of air-ground data link operations. This report addresses the benefits of using the mode select (Mode S) beacon system as an alternative for replacement of existing air traffic control beacon interrogators.</p>					
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FOREWORD

This report was prepared by the Department of Transportation, Federal Aviation Administration, office of System Engineering to describe the Mode S alternative for replacement of existing air traffic control beacon interrogators. A separate study is being undertaken of all alternatives, in addition to Mode S, that may be suitable candidates for replacing existing ATCBI interrogators. This report, however, describes only the operation of the Mode S subsystem and identifies benefits that the Mode S system provides to the National Airspace System (NAS) for surveillance and data link operations.

Other contributors to the report include the Martin Marietta Corporation, Air Traffic Systems, the Massachusetts Institute of Technology (MIT) Lincoln Laboratory, and the MITRE Corporation.

CONTENTS

	<u>Page</u>
Executive Summary	1
1.0 Introduction	3
2.0 Abbreviated History of Mode S Development	4
3.0 ATCRBS and Mode S Surveillance Descriptions	6
4.0 Surveillance Benefits Related to Mode S Sensor Installation	11
5.0 Unique Benefits Associated With Mode S Transponder Equipage	13
6.0 Mode S Data Link	18
7.0 Summary	32
8.0 Glossary of Acronyms	34
9.0 References	36

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EXECUTIVE SUMMARY

The present Air Traffic Control Radar Beacon System (ATCRBS) has inherent limitations which can degrade its usefulness as a surveillance tool in high-density airspace. These limitations include sensitivity to synchronous garble and the inability to assign unique identities to more than 4096 aircraft simultaneously.

The Mode S surveillance system was developed to expand the capabilities of ATCRBS, while still retaining interoperability during a transition period in which both Mode S and ATCRBS equipment are in simultaneous use. Mode S is currently being implemented into the National Airspace System (NAS) and has been adopted as the secondary surveillance radar (SSR) standard of the future by the International Civil Aviation Organization (ICAO).

The Mode S includes both surveillance and data link functions. Surveillance is performed both according to ATCRBS protocols and according to a set of selective address protocols in which every aircraft equipped with a Mode S transponder is interrogated individually.

As each Mode S aircraft is serially interrogated, message packets may be appended to the basic surveillance interrogations/replies in order to implement the data link function. Messages containing up to 1280 bits may be exchanged between each Mode S aircraft and the ground sensor during each scan. Mode S offers a cost-effective data link for ground-air-ground communication. This capability can serve most aircraft operations over the continental United States (CONUS). Other data link media will be used for oceanic operations. Mode S provides interoperability with other data link services conforming to the Open Systems Interface (OSI) standard through an Aeronautical Telecommunications Network (ATN).

The Mode S ground sensor installation substantially improves air traffic surveillance within NAS. Interrogation rates are substantially reduced to ATCRBS transponders, which reduces the amount of asynchronous false replies unsynchronized in time (FRUIT) and increases transponder availability. Within a Mode S sensor, monopulse processing of ATCRBS replies and improved surveillance processing also reduces, but does not eliminate, sensitivity to synchronous garble.

Surveillance effectiveness in NAS is further enhanced by increasing Mode S transponder equipage. Mode S aircraft can be uniquely identified by a code derived from the registration number or other numbering scheme, which is independent of the Mode A code selected by the pilot. Mode S aircraft in roll call surveillance are immune to synchronous garble. Error detection, error correction, and adaptive reinterrogation built into Mode S protocols reduce sensitivity to ATCRBS interference and increases the overall link reliability. Mode S transponders are specified to tighter tolerances than older ATCRBS transponders, and typically exhibit less variation in such parameters as downlink frequency and turnaround time. Overall surveillance accuracy is improved by up to a factor of four, relative to ATCRBS. A homogeneous Mode S technology will offer improved safety in NAS at a rate directly proportional to the risk-mitigating factors attributable to Mode S technology.

The Mode S data link protocols and architecture were created with the reliability and resistance to error necessary for performing ATC applications requiring transmission of safety critical data. Using the Mode S data link function, a pilot may access weather and flight information services, flight safety services, automated terminal information services, initial connection services, and Automated En route Air Traffic Control (AERA) air traffic control (ATC) connection mode services. The reliability of this data link service is enhanced by correlation of the Mode S data link and surveillance functions. The reliability, performance, and cost-effectiveness demonstrated by Mode S make it the FAA's primary choice for ATC data link services.

The Mode S sensors will be available in the near term. Sensors are currently in production testing and will become operational in early 1993. An initial acquisition will result in deployment of Mode S sensors at 133 facilities. The FAA is performing studies to determine if additional sensors are required for NAS.

1.0 INTRODUCTION

Air traffic control (ATC) is primarily interested in assuring adequate separation between aircraft in a safe and orderly fashion. To provide such separation in an increasingly crowded airborne environment, ATC must have timely and accurate surveillance information, as well as a reliable air-to-ground communications link. The mode select (Mode S) beacon surveillance system is being implemented as an evolutionary improvement to the existing ATCRBS system to guarantee that adequate surveillance and communications are provided, even in the face of projected increases in traffic density in many parts of the United States and overseas.

This report identifies the characteristics of the Mode S system which make it the preferred alternative for supporting NAS surveillance requirements well into the next century. A combination of historical perspective and technical description is provided to make clear both the background and the benefits of Mode S. First, a brief synopsis of the development of the Mode S surveillance system is given in Section 2.0. Section 3.0 provides an overview of the operation of both ATCRBS and Mode S systems to highlight their operational differences. Next, the surveillance advantages of Mode S are described in two parts. Because the ground sensor installation is expected to lead airborne Mode S transponder equipage by several years, Section 4.0 discusses the benefits which will be realized solely as a consequence of Mode S ground sensor installation. These benefits include a reduction in asynchronous interference, reduced sensitivity to synchronous garble, and more accurate and reliable surveillance. However, there are fundamental limitations to ATCRBS which can only be removed through conversion of ATCRBS transponders to Mode S. Section 5.0 details why Mode S ground sensor installations do not provide complete immunity to synchronous garble and other ATCRBS deficiencies, and describes the advantages realized as a consequence of near-universal Mode S transponder equipage. The Mode S data link is described in Section 6.0.

2.0 ABBREVIATED HISTORY OF MODE S DEVELOPMENT

In the early 1970's, the aviation communities in the United States and overseas recognized that ATCRBS has inherent limitations which degrade its usefulness as an ATC surveillance tool. These limitations include an unavoidable sensitivity to synchronous garble and the inability to assign unique identities to more than 4096 separate aircraft. These limitations had little impact in the early days of beacon surveillance radar, before densities of transponder-equipped aircraft approached 0.1 to 0.3 aircraft per square nautical mile (nmi) in areas such as the Los Angeles basin. However, it became evident that projected traffic increases would tax ATCRBS surveillance unacceptably. In the United States and United Kingdom, research and development of a "super beacon" was begun to find an evolutionary replacement for ATCBI equipment which would meet the challenge of providing adequate surveillance in high-density airspace. A key feature of the new beacon surveillance system was the capability to selectively interrogate individual aircraft, even when several aircraft were simultaneously within view of the ground sensor.

Early in the Mode S development cycle in the United States, the Federal Aviation Administration (FAA) developed a feasibility model of the discrete address concept. This concept was initially called the discrete address beacon system (DABS). It was developed and tested through 1974 and resulted in the publishing of a performance specification. In 1976, a competitive contract was awarded for three engineering models which were delivered to the FAA Technical Center (FAATC), Atlantic City, NJ, commencing in 1978. These engineering models were thoroughly tested by the FAATC, including joint flight testing with the U.S military between 1978 and 1980. These tests demonstrated that Mode S is completely compatible with existing civil and military ATC systems. Following the technical testing, the operational concept was validated in field tests with FAA air traffic controllers. During this period, ICAO and RTCA, Inc. were also active (and have continued to be active) in helping to develop Mode S Standards and Recommended Procedures (SARP) and Minimum Operational Performance Standards (MOPS).

The FAA issued a contract in 1984 for 137 systems (133 operational sites and 4 support units) with deliveries commencing in 1991 and continuing through 1996. These Mode S systems will provide coverage to 108 major airport terminal areas, and the remaining 25 will support the en route structure above 12,500 feet above ground level (AGL).

Current planning indicates that additional beacon interrogator systems are required in NAS after the first buy of Mode S systems are deployed. These additional systems will replace logistically insupportable ATCRBS equipment, support new qualifying site requirements, and extend the en route coverage down to 6000 feet AGL.

3.0 ATCRBS AND MODE S SURVEILLANCE DESCRIPTIONS

Mode S has evolved as a follow-on to the existing ATCRBS surveillance system, designed to substantially improve the quality of ATC ground-to-air surveillance, while maintaining complete compatibility and interoperability with ATCRBS. To compare and contrast ATCRBS and Mode S, an overview of the important characteristics of each is presented in the following paragraphs. Discussion of the benefits which result from Mode S is included in Sections 4.0 and 5.0.

A primary Mode S design requirement was assurance that the system could be implemented in an evolutionary manner, such that the existing ground and airborne equipment could continue to operate during an extended transition to an all-Mode S environment. For this reason, Mode S is capable of common-channel interoperability with the current ATCRBS. Mode S uses the same interrogation and reply frequencies as ATCRBS, and the signal formats have been chosen to minimize mutual interference between Mode S and ATCRBS.

3.1 DESCRIPTION OF ATCRBS SURVEILLANCE

ATCRBS surveillance interrogations are periodically transmitted from a rotating directional antenna. The antenna coverage typically extends from 0 to 50 degrees in elevation, and has a azimuthal beamwidth of 2 to 3 degrees. Interrogations are produced by modulating a radio frequency carrier with short (800 nanoseconds) pulse pairs in which spacing is either 8 microseconds for a Mode A (identity) interrogation, or 21 microseconds for a Mode C (altitude) interrogation. A typical interrogation rate or pulse repetition frequency (PRF) is between 200 and 450 interrogations per second. The scan period (time for one antenna revolution) is 4.5 seconds for terminal area surveillance, and 10 to 12 seconds for en route coverage. The uplink carrier frequency is 1030 MHz.

ATCRBS surveillance, like all beacon radar systems, requires that aircraft be equipped with a transponder capable of decoding the uplink interrogations, and replying with the appropriate formats. After detecting an uplink interrogation, and after a predetermined turnaround delay, a transponder transmits a 12-bit, pulse-amplitude modulated reply, which is broadcast omnidirectionally, on a downlink frequency of 1090 MHz. Depending whether the reply is mode A or mode C, the reply contains either the identity or altitude of the aircraft, respectively. The Mode A identity is preselected by the pilot from one of the 4096 available discrete codes. Aircraft which are equipped with an altitude encoder report altitude. Aircraft without an altitude encoder reply only with ATCRBS bracket pulses.

Slant range is estimated by the ground sensor by dividing the time interval between the transmission of the interrogation and the receipt of a reply (minus the known transponder turnaround time) by the speed of light. Azimuth is estimated with a sliding window detector. As the antenna rotates, the antenna azimuth at which aircraft replies are first detected is noted, along with the antenna azimuth at which aircraft replies cease. By averaging the leading and trailing azimuth, an estimate of the actual aircraft azimuth can be obtained. To achieve acceptable accuracy, a continuous stream of replies must be received from an aircraft while the beam sweeps across it. Typically, between 15 and 20 replies per beam dwell must be received from an aircraft. Both Mode A and Mode C replies must be received for the sensor to locate an aircraft in range, azimuth, and altitude. The software system which processes the detected replies to form output target reports is called Automated Radar Terminal System (ARTS) in terminal control areas, and Common Digitizer (CD) in en route control areas.

3.2 DESCRIPTION OF MODE S SURVEILLANCE

Mode S surveillance has two basic functions as a result of the requirement for interoperability with ATCRBS sensors and transponders. First, there is an ATCRBS processing function, capable of interrogating ATCRBS transponders and decoding ATCRBS replies. Second, there is a selective address, or Mode S, function which interacts solely with Mode S transponders. The selective address feature allows a Mode S ground sensor to individually poll Mode S transponders, even when several transponders are simultaneously within view. Each interrogation interval includes a period devoted to ATCRBS surveillance and a period devoted to Mode S acquisition and surveillance.

3.2.1 ATCRBS Monopulse Processing Subsystem of Mode S

ATCRBS processing within a Mode S ground sensor is required to locate and track aircraft equipped only with an ATCRBS transponder. Such processing differs from the present ATCRBS sensors in two important ways. First, azimuth is estimated using a monopulse technique. Second, more extensive surveillance processing is used to improve the accuracy of the reported position, identity, and altitude of each aircraft.

In monopulse azimuth processing, the receive antenna is configured to have both a sum and difference pattern. By taking the ratio of difference to sum for each pulse, a separate estimate of each pulse's angle of arrival is obtained.

Simple processing is used to combine the angle of arrival from each pulse to obtain a reliable estimate of the angle of arrival of a single reply (group of pulses from the same aircraft). The off-bore-sight angle of arrival is then added to the instantaneous shaft angle of the rotating antenna to form the total estimate of the aircraft bearing from the ground sensor. It is possible to obtain reliable azimuth estimates even when some or all of the pulses within a reply are garbled or missing, and 2 or 3 replies per scan are usually sufficient for high-quality azimuth estimates. However, the pulse repetition frequency (PRF) is usually selected to provide run lengths between 4 and 5 to support code detection.

While an aircraft is within the beam, reply-to-reply processing is performed to group the successive replies from the same aircraft. The grouped replies are termed raw target reports. After the beam rotates past an aircraft, surveillance processing is performed to obtain output target reports. Surveillance processing involves comparing the raw target reports with stored track files, which are maintained for all detected aircraft. The output reports represent the best estimate of the position, altitude, and mode A code for each target which is determined not to be the result of garble or known reflectors.

3.2.2 Selective Addressing Feature of Mode S

Mode S includes the capability to recognize up to 16 million unique addresses, which allows each aircraft presently in existence to be assigned its own unique address. The Mode S address for a given aircraft is set when the Mode S transponder is installed, and cannot be changed from the cockpit. Mode S addresses are derived from the registration number or other numbering scheme.

The unique identity of each Mode S aircraft is fundamental to roll call surveillance, which is the process by which Mode S sensors serially poll each aircraft within view of the sensor. By design, a Mode S transponder will not respond to a roll call interrogation which is not specifically addressed to that transponder. Therefore, roll call surveillance is performed by scheduling interrogations according to three criteria. First, a list must be maintained of all Mode S aircraft currently under surveillance, and at least one interrogation per scan must be scheduled for each aircraft. Second, the position of each aircraft must be predicted with sufficient accuracy so that the scheduled interrogation can be timed to coincide with the time that the rotating beam is illuminating the aircraft. Third, when multiple aircraft are simultaneously within the beam, their interrogations are range-ordered such that their replies will not overlap at the sensor.

Roll call surveillance is only effective for aircraft which are already known to the sensor. To acquire unknown Mode S aircraft, a sensor periodically broadcasts a Mode S all-call interrogation. Any Mode S transponder which has not been specifically commanded to ignore all-call interrogations will reply. Once an aircraft has been identified by the sensor, the aircraft Mode S address is added to the sensor roll call list, and the transponder is commanded to ignore any further all-call interrogations from that sensor in a process called lockout. The lockout status of a transponder is controlled by the sensor. A sensor may lockout aircraft to its own all-call interrogation or all-call interrogations from surrounding sensors. The method of operation is site adaptable and depends on whether the sensors have inter-sensor communications implemented. As long as the aircraft is on the roll call list of a sensor, a command to continue lockout status is included in each roll call interrogation. As the aircraft nears the edge of a particular sensor's coverage, the sensor will remove the lockout status to allow an adjacent sensor to acquire the aircraft. Finally, if for some reason a sensor ceases to interrogate an aircraft without specifically removing the all-call lockout, the transponder automatically terminates lockout after a short time-out period (typically about 18 seconds).

If aircraft are located close enough to one another that their all-call replies interfere at the sensor, a statistical acquisition process is used to randomize the probability that the transponders will respond. This increases the probability that subsequent all-call replies will be received in the clear. As each aircraft is acquired it is placed on the roll call list, and is locked out to subsequent all-call interrogations.

In addition to the unique address assigned to each Mode S transponder, each Mode S sensor may be assigned one of 15 discrete addresses. The sensor address is included with each interrogation so that aircraft may be directed to reply only to interrogations from specific sensors.

3.2.3 Differences between Mode S and ATCRBS Transponders

Roll call surveillance is only possible with Mode S-equipped aircraft. While Mode S transponders are capable of responding in ATCRBS mode in response to interrogations from ATCRBS sensors, they have several differences from ATCRBS transponders. First, the specifications for Mode S transponders manufactured for operation above 15,000 feet allow a tolerance of ± 1 MHz at the downlink frequency of 1090 MHz. Second, Mode S transponders can detect the difference between ATCRBS interrogations from ATCRBS or Mode S sensors, and all-call Mode S interrogations from Mode S sensors. The transponder will not respond to Mode S all-call interrogations from Mode S sensors once the sensor places the transponder in a lock-out mode.

Third, Mode S transponders typically employ newer technology than many older installed ATCRBS transponders. Fourth, Mode S reply formats provide for both altitude (if equipped) and aircraft Mode S identity in each surveillance reply, which removes the need for multiple replies from aircraft for a complete position and altitude update. Finally, Mode S interrogations and replies are parity encoded to offer error detection on the uplink, and both error detection and limited correction on the downlink.

4.0 SURVEILLANCE BENEFITS RELATED TO MODE S SENSOR INSTALLATION

The installation of Mode S ground sensors offers surveillance benefits even in the absence of Mode S transponders. These benefits derive primarily from monopulse azimuth processing and from the more sophisticated surveillance processing employed in the ATCRBS subsystem of a Mode S sensor.

4.1 REDUCED ASYNCHRONOUS INTERFERENCE FRUIT

When aircraft are simultaneously within view of multiple sensors, each sensor receives not only replies in response to its own interrogations but also those due to other sensors. These extraneous replies are referred to as false replies unsynchronized in time (FRUIT). FRUIT may overlap valid reply pulses resulting in smearing, or interference, that make reply pulses unintelligible. This condition is known as garble. FRUIT reply rates as high as 20,000 per second, or 1 per 50 microseconds, are not uncommon in airspace with a high density of ATCRBS transponders within view of several ATCRBS interrogators. Since ATCRBS replies are 20.3 microseconds long, the chance of garble due to FRUIT is quite high. Monopulse processing allows the run length of ATCRBS replies to be reduced from 15 to 20 to 4 to 6, or equivalently the PRF to be reduced by about a factor of four. Given no change in the density of equipped aircraft, this immediately reduces the FRUIT density by a factor of four.

4.2 INCREASED TRANSPONDER AVAILABILITY

Transponders can only reply to one interrogation at a time. Associated with each reply is a recovery time of up to 125 microseconds, during which all interrogations are ignored. This process is known as transponder capture. In cases of multiple coverage, several sensors may be simultaneously interrogating the aircraft. Transponder capture may lead to loss of replies at some or all of these sensors. This problem is more severe with sliding window detectors, both because of the higher PRFs associated with sliding window detectors, and because of the azimuth errors and azimuth errors caused by gaps in the reply stream to a sliding window detector.

To control power dissipation, most transponders have circuits which reduce the receiver sensitivity as the average reply rate approaches 1200 to 2000 replies per second. This has the effect of denying coverage to more distant sensors while continuing to reply to nearby sensors. The reduced PRF associated with monopulse processing in Mode S sensors increases the number of sensors which can maintain coverage of an aircraft before limiting sets in.

4.3 REDUCTION IN SYNCHRONOUS GARBLE

ARTS processing offers little protection against synchronous garble. The longer run length of ARTS generally guarantees adequate protection against FRUIT-induced garble and other effects which can produce transient false targets. However, because aircraft may remain close enough to synchronously garble one another for periods extending over several scans, longer run length does not reduce sensitivity to such interference.

A Mode S sensor's capability of estimating the azimuth of each pulse within a reply, combined with the extensive surveillance processing used in ATCRBS target report formation, substantially increases the blip/scan ratio (also known as the track update probability) relative to ARTS for aircraft in synchronous garble situations. Test results have shown an increase in blip/scan from 86.9 percent to 96.6 percent in comparisons between ARTS and monopulse ATCRBS processing of aircraft in crossing situations.

The additional surveillance processing performed in the Mode S sensor is particularly important in maintaining surveillance on aircraft which are in severe garble situations. Although altitude information may be lost for several scans, as long as some high-confidence Mode A bits are decoded at least the position and Mode A code are likely to be reported accurately. This is because range and azimuth may be estimated based on a portion of a single reply, while low-confidence Mode A bits may be corrected from the associated track file. The fact that Mode A can be improved based on the stored track file, but not Mode C reports, reflects both the expectation that the Mode A identity of an aircraft is expected to change far less frequently than its altitude, and the FAA air traffic control requirement for un-edited altitude data to guarantee altitude separation.

5.0 UNIQUE BENEFITS ASSOCIATED WITH MODE S TRANSPONDER EQUIPAGE

The most serious problem that cannot be solved with monopulse-only radar systems is elimination of synchronous garble. While monopulse processing of ATCRBS replies reduces FRUIT rates and increases azimuth reliability and accuracy, it does not fundamentally remove the problem of synchronous garble. Thus, in situations involving a large number of aircraft in a small amount of airspace, synchronous garble will continue to limit the capabilities of ATC functions. For instance, the use of radar for altitude separation in holding stacks is impractical due to occasional altitude surveillance dropouts which can extend for as long as 30 to 40 seconds due to synchronous garble. Furthermore, with expected traffic growth, particularly in areas of high traffic density and multiple sensor coverage, the use of monopulse processing only delays the time when surveillance will again be unacceptably degraded due to synchronous garble.

In addition, monopulse processing of ATCRBS does nothing to alleviate the problem of Mode A code shortage in crowded airspace. Only Mode S, capable of recognizing up to 16 million distinct addresses, can guarantee unique identities to all aircraft under both VFR and IFR. Mode S also supports improved Traffic Alert and Collision Avoidance System (TCAS) processing and compliance with ICAO standards.

5.1 HOMOGENEOUS MODE S GROUND AND AIRBORNE ENVIRONMENT

A homogeneous Mode S ground and airborne environment eliminates synchronous garble. Roll call surveillance, which is only possible between Mode S ground sensors and Mode S-equipped aircraft, inherently eliminates any form of synchronous garble. Since only one aircraft replies at a time, there is no possibility for mutual interference. Even in cases where aircraft geometry produced synchronous garble severe enough to induce gaps on the order of 30 to 50 seconds in monopulse ATCRBS surveillance, Mode S surveillance has been shown to be essentially flawless in both position and altitude reporting.

Non-Mode S transponder equipage will be allowed for general aviation. Mode S transponder equipage may be required in specified airspace. During the transition period, in which significant numbers of ATCRBS transponders will be present in the Mode S-specified airspace, ATCRBS FRUIT-induced garble can also degrade Mode S replies. To combat this, error detection and correction is part of the Mode S reply decoding process in a Mode S sensor. As long as the garble-induced errors are contained within a 24-bit section of the reply (which corresponds to the time a single ATCRBS FRUIT reply lasts), the errors can be corrected. This feature greatly improves the reply reliability in the presence of ATCRBS FRUIT. The expected undetected error rate is less than 1 per 10⁷ messages with Mode S.

5.2 MODE S SUPPORT OF INCREASED TRAFFIC DENSITY

Because Mode S transponders can be commanded from the ground to reply only to interrogations from certain sensors, the capability exists to add sensors in high-density areas without increasing FRUIT or decreasing transponder availability. Suppose that a single sensor presently provides coverage in an area in which density has increased to the point where the traffic capacity of the sensor has been reached. A second sensor may be located nearby with overlapping coverage and the coverage of each sensor adjusted to share the traffic load. Mode S equipped aircraft can be manipulated to reply to only one sensor .

The sensor coverage can be adjusted in one of three ways as described below.

First, the aircraft can be commanded to ignore all-call interrogations to a particular sensor based on the location of the aircraft. The lockout is initiated through use of a non-selective all-call lockout protocol. This means that an aircraft will be invisible to all sensors except the sensor selected to provide coverage. When an aircraft is about to enter the coverage of another sensor, the transponder is selectively unlocked based on location so that the transponder will reply to the adjacent sensors all-call interrogations. At this time, the aircraft will not be invisible to the adjacent sensor. By changing which sites the aircraft is commanded to reply to, the aircraft can be acquired by a sequence of sensors as a function of the aircraft position.

A second method is to use multi-site all-call lockout protocol which locks out transponder replies to all-call interrogations based on sensor address. Since adjacent sensors have different addresses, the transponder would reply to the adjacent sensor all-call interrogations.

The third method is to use sensor netting. With this method, sensors are netted such that surveillance information is exchanged between them, an aircraft can be handed off, or deleted from the roll call list of one sensor and added to the next, such that all-call acquisition is never necessary once the aircraft is on the roll call list of one sensor within the inter-netted group. This latter method of intersensory coverage has the advantage of reducing all-call FRUIT and garble.

It is important to note that the analogous capability does not exist with any surveillance system which relies solely on all-call surveillance. Although an ATCRBS sensor may be limited in processing replies outside a fixed range interval, no method exists to limit aircraft replies to interrogations from all ATCRBS sensors within view of the aircraft. These replies will add to the FRUIT and garble environment of the area. It would be impossible, for instance, to decrease the interference seen by a single ATCRBS sensor by placing another ATCRBS sensor nearby.

5.3 MODE S IMPROVEMENT IN ESTIMATE OF POSITION, IDENTITY, AND ALTITUDE

The monopulse processing associated with Mode S improves the azimuth estimate in a similar manner to improved detection of ATCRBS replies. However, there are additional benefits unique to Mode S. First, each bit in a Mode S reply is coded as a 1 or a 0, depending on whether a pulse is located in the first or second half of a bit location. This means that each reply contains a pulse in each bit location, regardless of the contents of the reply. In contrast, an ATCRBS reply of all zeroes would contain only framing pulses. Because the monopulse processor is guaranteed a constant number of pulses in Mode S replies, the azimuth accuracy of Mode S surveillance is data independent. Second, because a Mode S reply contains both the Mode S identity and aircraft altitude, no possibility for target splitting occurs as a function of differential Mode A/Mode C transponder turnaround time. The net result is that the surveillance accuracy for Mode S is approximately a factor of four better than ARTS-based ATCRBS.

5.4 ELIMINATION OF THE NEED FOR NON-DISCRETE CODES

ATCRBS is inherently limited to the use of no more than 4096 discrete codes, because of the 12 bit reply format. While this did not cause significant problems when ATCRBS was first introduced, in today's more crowded airspace it is possible to reach a saturation point when there are no assignable codes available within the coverage of a single sensor. Also, VFR traffic is commonly assigned Mode A code 1200. The presence of non-discrete codes complicates the tracking algorithms of the sensor and may increase a controller's workload. Also, when aircraft must change codes while flying from one coverage sector to another to avoid duplicate codes within a sector, the possibility for error in the handoff process is introduced. A homogeneous Mode S environment eliminates the need for non-discrete codes.

5.5 IMPROVED TRANSPONDER PERFORMANCE WITH MODE S

Mode S transponders use more modern technology and the specification requires more stringent limits on performance for Mode S transponders operating above 15,000 feet in areas such as downlink frequency variation and variations in transponder turnaround time. Because of the advantages, the overall surveillance accuracy is expected to improve regardless of whether ATCBI or Mode S sensors are used.

Variations in transponder turnaround times for Mode A and Mode C can produce splits in ATCRBS target reports. The more modern Mode S transponders are expected to exhibit less variation in turn-around time than older installed ATCRBS transponders.

Off bore-sight azimuth estimates using monopulse processing are typically sensitive to frequency variations in the downlink signal. The monopulse estimate associated with replies from Mode S transponders is expected to be less subject to frequency-induced bias than monopulse processing of replies from older, less accurate ATCRBS transponders.

In summary, there is some improvement to surveillance accuracy simply by virtue of the natural decrease in age of the installed transponder population as a consequence of the conversion to Mode S.

5.6 MODE S SUPPORT OF INCREASED CAPACITY IN THE NAS

The FAA expects that one of the ways in which the future NAS capacity can be expanded will be through decreasing the required separation between aircraft, particularly in the terminal area. Reducing separation will mostly be driven by factors other than surveillance performance. However, the positional accuracy provided by Mode S is high enough that surveillance will not be a limiting factor in the foreseeable future. For example, the effectiveness of many automation algorithms (e.g., blunder detection during independent parallel approaches) requires high-quality surveillance to provide a high probability of detection and low false alarm rates. A surveillance system free from synchronous garble is essential to provide high-quality position and altitude information in high-density airspace. This performance is achieved with Mode S discrete addressing and monopulse processing.

5.7 SAFETY IMPROVEMENTS

A homogeneous Mode S environment offers improvements in safety. Safety benefits accrue to the aviation community at a rate directly proportional to the risk-mitigating factors attributable to the Mode S technology improvements.

5.7.1 Minimized Probability of Violating Separation Standards as a Result of ATCRBS Operation Limitations

Mode S technology virtually eliminates the incidence of lost flight "tracking" caused by synchronous garble, thereby allowing positive, continuous control. Mode S also provides the target positional data accuracy needed to maintain separation standards.

5.7.2 Potential Airspace Capacity Increases with No Risk of Reducing Safety Due to Equipment Performance

The increased accuracy and interference-free operation of Mode S provides a possibility for evolutionary capacity improvements as the ATC environment is further automated.

5.7.3 Reduced Probability of Human Error Resulting from the Necessity to Compensate for Equipment Limitations and Procedural Complexity

Special identification procedures have to be initiated to identify aircraft because of uncertainty resulting from false alarms, garble, reflection, multi-path target dropout, or smearing. With Mode S operation, less demand is put on the controller to resolve these situations in which surveillance deficiencies may have contributed to a confused picture of the ATC situation.

6.0 MODE S DATA LINK

6.1 OVERVIEW OF AIR-TO-GROUND COMMUNICATIONS

Air-to-ground communications devoted to maintaining safety and schedules of civil aviation flight can be divided into two general classes: Air Traffic Services Communications (ATSC) and Aeronautical Operational Control (AOC). ATSC messages are used for directing traffic to ensure adequate separation of aircraft. Examples of ATSC messages include clearances, clearance acknowledgments, and altitude and heading assignments. In the United States, ATSC messages are almost exclusively handled over voice radio facilities owned and operated by the FAA. AOC messages enable flight crews to exchange information concerning weather conditions, in-flight delays, maintenance problems, gate assignments, etc., with company personnel on the ground. AOC messages are presently handled using voice and digital communications over the privately operated Aircraft Communication and Reporting System (ACARS).

ARINC and FAA-operated voice radio facilities presently operate near full capacity within the busier airspaces in the United States. For instance, at O'Hare International Airport during periods of poor visibility, airport capacity is often limited by insufficient communications capacity on the ground control frequencies. In other examples, pilots may have difficulty breaking into the tower or approach frequency with requests or position reports during particularly busy arrival or departure periods. To reduce the burden on voice channels, the FAA is undertaking to transfer routine, repetitive, and well-defined messages from voice channels to a digital data link. In addition, the availability of a digital data link will make it possible for the FAA to offer new services which will increase pilot situational awareness, and provide more up-to-date hazardous weather information in cockpits.

Presently, part of the FAA's planned NAS upgrade is to implement the Mode S data link as the primary medium in the near term for digital air-to-ground ATC communications. Mode S data link will be available with implementation of the initial buy of Mode S sensors through use of the ground-based Data Link Processor (DLP) Build 1. The Mode S data link will support all proposed DLP functions and will operate as a subnetwork within the ATN. DLP functions are described in more detail in subsection 5.3.

The Mode S data link offers an important benefit of increasing the use of the RF spectrum already assigned to the FAA. The VHF spectrum is valuable and is in great demand by many users outside the aviation community. In some areas, the lack of available spectrum within the aviation band (108.1 MHz - 135.975 MHz) limits capability to add instrument landing systems (ILS) to airports which would otherwise qualify for such systems. The Mode S data link offers digital air-to-ground communications within the band (1030 MHz to 1090 MHz) presently allocated to surveillance, without requiring additional spectrum or reallocation within the aviation band.

6.2 MODE S DATA LINK DESCRIPTION

Mode S surveillance makes use of a selective address mechanism to ensure that replies from multiple aircraft do not interfere at the sensor. The simplest class of digital data link is implemented by a 56-bit message block to individually addressed interrogations and replies already in use for surveillance. These are called Comm A (uplink) and Comm B (downlink) formats.

A higher capacity channel is achieved, while minimizing overhead, by using data link-specific formats which have either 76-bit (uplink) or 80-bit (downlink) data segments, and which can be linked together such that up to 16 segments can be transmitted with a single acknowledgment. These data link-specific formats are called uplink and downlink extended-length messages (U-ELM and D-ELM, respectively). Broadcast uplink and downlink messages (directed to all aircraft or sensors within range) are also available.

Mode S transponders are categorized into one of four classes, according to their data link capability. Table 6.2-1 summarizes the data link capability of each class. All classes are recognized for use in the U.S. by the FAA and ICAO. Class 1 is not recognized by ICAO for international use.

Mode S transponders suitable for general aviation, with up to Class 3 capability, are expected to be available for less than \$5000 each within the next 5 years. Mode S transponders with no data link compatibility presently list for \$3800 and may be available at a substantial discount.

In the following discussions, all uplink transmissions (sensor-to-airborne transponder) are termed interrogations. All downlink transmissions are termed replies. As previously noted, communications message blocks may be appended to either interrogations or replies.

Table 6.2-1 Transponder Data Link Capability

TRANSPONDER TYPE	SURVEILLANCE	UPLINK	DOWNLINK	MULTISITE
Class 1	Mode S Surveillance Only			
Class 2	Mode S Surveillance	COMM A	COMM B	Yes
Class 3	Mode S Surveillance	COMM A U-ELM	COMM B	Yes
Class 4	Mode S Surveillance	COMM A U-ELM	COMM B D-ELM	Yes

6.2.1 Standard-Length Message Formats

Transponders with Comm A/B capability (Class 2 or higher) make use of existing surveillance interrogation/reply pairs to implement a data link. A 56-bit data block is inserted into the normal 56-bit surveillance interrogation/reply. The resulting interrogation or reply is 112 bits long. All Comm A messages elicit either a surveillance or Comm B reply, which provides a technical acknowledgment that the uplink message was successfully received.

Comm B (downlink) messages can be initiated either from the ground or the air. In the first case, the ground sensor sets a field in an interrogation which indicates to the transponder that the contents of a specific 56-bit transponder register should be appended to the next downlink reply (forming a Comm B reply). No acknowledgment is given since, if the ground does not receive the reply, the request is repeated. For airborne-initiated Comm B messages, a bit is set in the surveillance replies which indicates to the sensor that the transponder has a message to relay to the ground. The sensor requests readout of the downlink message on the next interrogation. In this case an acknowledgment is necessary from the sensor, and is provided within the interrogation following receipt of the Comm B message.

A Comm B Broadcast mode is also available which allows the aircraft transponder to broadcast to all sensors in the area. None of the sensors is locked-out. To initiate a Comm B Broadcast, an aircraft transponder notifies all sensors in the area that a Comm B message is available. The sensors can then request a downlink. This mode is available for a fixed time period.

Mode S protocol allows up to four Comm A or Comm B messages to be linked, to allow transmission of messages between 56 and 224 bits. Every segment of linked Comm A/B messages requires an interrogation/reply pair. Typically, a linked Comm A/B message will be transferred within one scan. At peak traffic densities a second scan may be required.

6.2.2 Comm A/B Equipage Requirements and Channel Capacity

Comm A/B capability (Class 2 or higher Mode S data link) requires minimal modifications to a surveillance-only Mode S transponder. A limited amount of buffering is necessary to support Comm A/B messages, and some additional software is required to handle the additional formats. Minimal modifications to the RF transmitter are expected, relative to a Class 1 transponder.

At worst case loading (32 aircraft within a 2.4-degree wedge), Comm A data link provides at least 112 bits (two messages per aircraft) per scan with a rotating sensor. In the terminal area (scan period = 4.8 seconds) this corresponds to 23 bps. More

realistic traffic density assumptions yield an expected uplink capacity of 93 bps (based on eight Comm A messages per aircraft per 4.8-second scan).

At typical traffic densities, at least four Comm B messages per aircraft per scan will be available, corresponding to a downlink channel bit rate of 47 bps.

6.2.3 Extended-Length Message Format

Additional data link capacity is available through the use of non-surveillance formats. These interrogation/reply formats, termed uplink ELM or downlink ELM, have 76-bit or 80-bit message information blocks, respectively, and are 112 bits long overall. Interrogations or replies may be linked such that up to 16 U-ELM or D-ELM message segments may be sent with a single acknowledgment. Depending on the surveillance load, the linked ELM segments can be transferred within one scan, or over a period of several scans. The capability to send up to 1216 (uplink) or 1280 (downlink) bits in one linked message greatly increases channel efficiency relative to Comm A/B messages which require an acknowledgment every 56 bits.

6.2.4 U-ELM Equipage Requirements and Channel Capacity

The addition of U-ELM capability greatly increases the uplink data capacity relative to Comm A/B-only channels. The capability to handle U-ELM requires a Class 3 or higher class transponder. The difference between a Class 2 and a Class 3 transponder is in the software and buffering capability. Negligible changes to the transponder RF transmitter are required. Manufacturers expect that a Class 3 transponder capability should add less than \$1000 to the cost of a Class 1 (surveillance-only) transponder.

Assuming at least one U-ELM per scan per aircraft, in addition to eight Comm A messages, the total expected data rate is 347 bps (assuming a 4.8-second scan period). It is important to note that this data rate may be achieved at all but the heaviest traffic densities.

6.2.5 D-ELM Equipage Requirements and Channel Capacity

Adding D-ELM capability to a transponder enables the highest data rate channel for both uplink and downlink. This is a Class 4 transponder. An RF transmitter with substantially higher average power is required to support the higher duty cycles associated with D-ELM messages. The cost of Class 4 transponders are expected to be substantially higher than general aviation (GA) Class 1, 2, and 3 transponders.

Assuming at least one D-ELM message per scan (in addition to the previous estimate of four Comm B messages), the resultant average downlink data rate is 313 bps, for a 4.8-second scan period.

6.2.6 Airborne Equipage Requirements and Cost for Mode S Data Link

The implementation of any air-to-ground data link will require two components in the aircraft: (1) a communications port (modem) to establish the physical connection and (2) some type of data link processor to interpret ATN messages and interface to onboard avionics. The onboard data link processor is expected to be independent of the particular air-to-ground physical data link. A Mode S transponder (Class 2 or higher) is the sole airborne equipage required to establish the physical data link connection.

The choice of transponder capabilities to be used will be dictated by the types of services desired, as well as cost. Most services of interest to GA pilots require no more than limited downlink capability, which makes Class 2 or 3 transponders appropriate for such aircraft. Use of data link for Air Traffic Control messages will require at least a Class 3 transponder. D-ELM capable transponders (Class 4) are expected only in high-end GA and air-transport cockpits. As noted in subsection 5.1, costs of Class 3 transponders are expected to be within \$1000 of a surveillance-only Mode S transponder. There are no transaction or user fees associated with use of the Mode S data link.

The Mode S transponder also has the capability to accommodate an Airborne Data Link Processor (ADLP) which provides an interface to the ATN router. ADLP is designed to provide two functions. The first function is a link-level router that provides protocol conversion and message routing for the Mode S data link. The router condenses the link-level protocol header and emulates a X.25 network interface. Data link messages can also be resegmented to fit the Mode S ELM and Comm B message formats. The second function is a network management function that determines the sensor from which messages are received. An associated Ground Data Link Processor (GDLF), located in the Mode S sensor's corresponding Air Route Traffic Control Center (ARTCC), will expand the protocol header and model the X.25 interface protocol.

6.2.7 Link Reliability

All uplink and downlink messages are subject to the same error checking and correcting (on downlink) protocols used in surveillance messages (as described in section 4.1), which reduce the chance of an undetected error to less than 1 per 10¹¹ 112-bit messages. After accounting for fades and vertical lobing of the sensor antenna pattern, the proportion of aircraft which are expected to reply successfully to interrogations at least once during any two successive scans is better than 99% out to 100 nmi, for a terminal sensor. The same performance is expected out to 160 nmi for an en route sensor (the longer range is due to the higher gain antenna in the en route sensor).

6.2.8 Mode S Data Link Channel Management

Interrogations to aircraft are scheduled according to when the aircraft are expected to be within the rotating beam aircraft range, and priority of pending surveillance or data link messages. Interrogations are generally prioritized as follows:

- 1) Class 1 Interrogations for altitude, ATCRBS ID, high-priority Comm A/B messages;
- 2) Class 2 High-priority U-ELMs;
- 3) Class 3 Additional (low-priority) Comm A/B messages;
- 4) Class 4 U-ELMs and D-ELMs.

Because Mode S interrogations and reply times are scheduled within the sensor, operation near the channel capacity limit is possible without the multiple retries needed in a collision sense/multiple access protocol. Furthermore, in the event of operation under conditions which may temporarily exceed the channel capacity, degradation is graceful rather than abrupt.

6.2.9 Comparison of Rotating Antenna and E-Scan Sensors

The initial installation of Mode S sensors will employ rotating fan beam antennas with 2.4-degree horizontal beamwidth and a 4.8-second scan period. Peak bunching of aircraft within the fan beam limits the maximum Mode S data link channel capacity, due to the constraints of processing all the replies from aircraft within the beam during a single beam dwell.

It is possible to increase Mode S channel capacity by replacing the rotating sensor with an electronically scanned (E-Scan) antenna. The E-Scan antenna effectively "separates" the aircraft by allowing the sensor to schedule interrogations at any time within a scan period, instead of just within one 33 microsecond beam dwell every 4.8 seconds. In scenarios where the sensor is not operating at the reply rate limits of 1000 per second for transponders operating under 15,000 feet and 1200 per second for transponders operating over 15,000 feet, averaged over four seconds, or the maximum suppression time (45 microseconds), set to avoid over suppression of ATCRBS transponders, use of the E-Scan antenna increases the uplink data rate to at least 1216 bps (one uplink ELM per second) for Class 3 and 4 transponders.

6.3 FAA DATA LINK PLAN

A digital data link communication capability is an integral part of the FAA's NAS enhancement plan. The data link will be used by air traffic controllers to communicate with aircrews, and will also enable aircrews to access various information services.

Advanced en route air traffic control Phase 2 (AERA 2) will use the data link to communicate ATC clearances to aircrews operating under instrument flight rules (IFR). The FAA has adopted the ATN architecture for the planned data link and is developing a DLP to provide processing and storage necessary to implement initial information services and ATN.

6.3.1 Aeronautical Telecommunications Network

The ATN was conceived to provide a means of transparent data transfer between aircraft and ground-based application processes. Communication-specific functions such as data link selection for a particular data link message and data link changeover as an aircraft transitions between coverage areas, are isolated from the application processes and performed by the ATN in providing the communications service. Thus, ATN enables development of applications that are independent of communications requirements relating to a specific data link or network. The ATN is being developed to use Mode S, satellite, and VHF data links applying inter-networking protocols. These protocols are being developed and coordinated with the RTCA and the ICAO. The protocols developed in accordance with International Standards Organization (ISO) Open Systems Interconnection (OSI) Reference Model.

6.3.2 Data Link Processor

A DLP is being developed for each Area Control Facility (ACF). The DLP will initially interface with automation systems providing weather and flight service information. The DLP will provide the following six basic weather and flight information services to aircrews using the Mode S surveillance system's data link capability beginning in 1992/1993:

- 1) Surface observations;
- 2) Terminal forecasts;
- 3) Winds and temperatures aloft forecasts;
- 4) Pilot reports;
- 5) Radar summaries;
- 6) Hazardous weather advisories.

Enhancements are planned and a DLP Build 2 (DLP 2) is scheduled for 1996. The DLP 2 includes full functionality for Mode S GDLP and the ATN router. DLP 2 will route ATC services (clearances) and flight safety services. Modifications will be required in ACF and ATCT automation systems (ACCC, TCCC, GDLP) to provide ATC services. DLP3 will provide a higher capacity system which supports the AAS environment and provide advanced weather services (e.g. graphics).

6.3.3 Data Link Services Description

This subsection provides a description of services that are currently planned and some that have been proposed (and in some cases demonstrated), but are not included in the FAA's Capital Investment Plan (CIP).

6.3.3.1 Weather and Flight Information Services

Weather and flight information services are all text-oriented services intended to increase safety by making information more readily available to aircrews before and during flight. (Note that Mode S does not provide data link coverage to aircraft on the ground.) They are transaction-oriented (request/reply) services and will be provided by DLP. Each request for an information service specifies a location identifier and results in the transmission of either the desired product or an error message (e.g., no data, bad request). All services except Notices to Airmen (NOTAM) will be available with the initial DLP capability.

1) Surface Observation

A surface observation (SA) provides ground weather conditions at the reporting station. SA messages include observation time, sky condition, ceiling, visibility, weather and obstructions to vision, barometric pressure, temperature, dew point, wind direction and speed, and remarks.

2) Terminal Forecast

A terminal forecast (FT) provides a 24-hour forecast for the immediate vicinity of the airport. The terminal forecast message projects the following conditions for specified time periods: sky condition, ceiling, visibility, weather and obstructions to vision, winds, cloud heights, and expectation of visual or instrument meteorological conditions.

3) Winds and Temperatures Aloft Forecast

The winds and temperatures aloft forecast (FD) message gives projected wind direction, wind speed, and temperature at the location for altitudes of 3000, 6000, 9000, 12000, 18000, 24000, 30000, 39000, 45000, and 53000 feet for the specified location.

4) Pilot Report

A pilot report (PIREP), or UA, is a report of weather conditions observed by a pilot in flight. These messages include sky cover, flight visibility, flight weather, and indications of icing or turbulence. Requests for PIREPs specify a location and may include optional filters to limit reports in altitude ranges or contents.

5) NOTAM

NOTAM messages provide information on the availability of ground equipment and facilities within NAS. They provide notice of equipment failures and runway closings. This service provides only class "D" NOTAMs (those that have not been formally published by the FAA).

6) Radar Summary

The radar summary (SD) is a low-resolution (22 nmi grid) pseudo-graphic showing a portion of the national precipitation map centered on a specified location. Precipitation intensity levels are denoted by numeric characters "1" through "6". Maps are generated by compositing radar data and are updated hourly.

7) Hazardous Weather Advisory

Hazardous weather advisories are issued by the National Aviation Weather Advisory Unit (NAWAU) to warn en route aircraft of the development of potentially hazardous weather conditions. These advisories include AIRMETs, SIGMETs, Urgent SIGMETs, and Convective SIGMETs. In addition, center weather advisories (CWA) will be supported as an enhancement for the DLP Build 2. Notice of availability of these advisories comes automatically with a request for any of the weather/flight information services described above.

6.3.3.2 Flight Safety Services

Flight safety services are text-oriented messages conveying real-time flight safety information to aircrews. There is only one flight safety service planned and it is a request/reply service.

1) Wind Shear Advisory

The wind shear advisory provides information on the presence of microburst or wind shear conditions at a specified airport. The information includes event type, location of event relative to a runway, gain or loss of winds across the event, and threshold wind direction and speed. A pilot must request this service for a specified airport and "service time." The pilot may request the service for only a specified runway and may request to discontinue the service. The wind shear advisory service will be implemented as an enhancement to the initial DLP Build 2.

6.3.3.3 ATC Request/Reply Services

ATC request/reply services provide text-oriented data link messages conveying information required for IFR aircraft.

1) Automatic Terminal Information Service

The Automatic Terminal Information Service (ATIS) is currently provided as a continuously repeating voice broadcast including weather, NOTAMS, hazardous weather advisories, and other remarks pertaining to a particular airport. The data link service will provide the same information to aircrews on a request/reply basis. ATIS data is generated at the control tower and forwarded to DLP for inclusion as a data link service.

6.3.3.4 Initial ATC Connection Mode Services

ATC connection mode services require that a communication network connection be established between an aircrew and an air traffic controller. A login procedure will be used to establish the connection. Once established, the following messages will be used to issue ATC clearances and provide a backup for voice communications between ATC and the IFR aircrew. Each of these messages requires an acknowledgment.

1) Transfer of Communication

The transfer of communications (TOC) message is an uplink message providing instruction to an aircrew to switch to a new radio frequency for voice communications. This message will also include an altimeter setting if the assigned or reported altitude is less than or equal to 18,000 feet.

2) Altitude Assignment

An altitude assignment message is an uplink message that instructs an aircraft to change to, or maintain, a specified altitude or range of altitudes. If the assigned or reported aircraft altitude is less than or equal to 18,000 feet, an altimeter setting will be included.

3) Altimeter Setting

This message reports the altimeter setting for a particular location. It is normally sent only in conjunction with TOC or altitude assignment.

4) Predetermined ATC

This is a set of pre-formatted messages for ATC to select for assignment of speed, heading, altitude, and crossing restrictions to IFR aircraft.

5) Communications Backup (Free Text)

This message is used to uplink or downlink text for a voice communications backup.

6.3.3.5 AERA 2 ATC Connection Mode Services

The following services have been proposed and documented in the AERA 2 system-level specification for implementation in the Area Control Computer Complex (ACCC). In some cases, these modify or replace the initial ATC services listed above. Each of these messages requires an acknowledgment.

1) Transfer of Communication

This message may be generated automatically by the ACCC or manually by ATC to direct an aircrew to switch to a new voice communications frequency.

2) On Frequency

This message is downlinked from an aircraft to notify ATC of a voice communications frequency change.

3) Clearance Delivery

This is a class of messages uplinked by ATC to alter an aircraft's clearance. Clearances include: altitude assignment; altitude assignment with restrictions; future altitude assignment; speed change; route change, with any future altitude and speed changes embedded; vector(s); and clearance limit/holding instructions.

4) Flight Plan Amendment Request

This message is a downlinked request from an aircrew to change a flight plan.

5) IFR Clearance Activation Request

This message is a downlinked request from an aircrew to activate a filed flight plan.

6) Time-of-Arrival Metering Goal

This is an automatic ACCC message sent to an aircrew to provide a position (fix) and time goal information to implement ATC-imposed en route delay.

7) Start Maneuver Reminder

This is an automatic ACCC message uplinked to advise an aircrew of the time or position of an imminent maneuver.

8) Top of Descent Preference

This message is sent automatically by ACCC to request a corresponding downlink message from an aircrew stating preferences for top of descent.

9) Top of Descent Reminder

This is an automatic message uplinked to advise an aircrew of the time and position of the top of descent.

10) Pilot User Preference Request

This is a downlink message from an aircrew requesting that the ACCC uplink a copy of its stored user preferences for that aircraft.

6.3.3.6 Other Proposed Services

The following services are not presently included within programs identified in the FAA's CIP. An analysis will be performed to determine which of these services would be included in subsequent issues of the CIP. Traffic information service has been demonstrated by Lincoln Laboratory.

1) Traffic Information Service

The Traffic Information Service (TIS) will provide information on the positions of aircraft within a specified height differential and radial distance of an aircraft requesting the service. The service will be provided on a continuous basis and will provide a graphic depiction of nearby traffic to an aircrew. The equipage and installation requirements are suitable for GA implementation.

2) Hazardous Weather Graphics

Hazardous weather graphics will be a service providing an aircrew with graphic depictions of areas of heavy precipitation, wind shear, and other pertinent weather-related hazards. The graphic display will be updated in real-time. Equipage and installation requirements are being developed for systems which are compatible with either GA or transport category cockpits.

3) Route-Oriented Weather

The route-oriented weather service will provide weather information to aircrews for points along a specified route.

4) Downlink PIREPs

Downlink PIREPs will be a service enabling an aircrew to file PIREPs during flight.

5) Downlink Winds and Temperatures Aloft

Downlink winds and temperatures aloft will be hosted in a facility where aircraft that are equipped to do so will provide data on wind and temperature measurements taken during flight. This data will be incorporated into the meteorological database, enabling a current observation to be made available for reference or for use in forecasts.

6) Downlink Trajectory Information

This message provides trajectory information from airborne computers, such as expected arrival time at fix, enabling improved performance of AERA 2 functions.

7.0 SUMMARY

The Mode S system provides two basic functions: surveillance and data link. The surveillance function provides interoperability with ATCRBS and Mode S equipment and selective addressing to poll Mode S transponders individually. Each Mode S sensor interrogation interval includes periods devoted to performing ATCRBS interrogation and Mode S interrogation separately. The data link function provides uplink and downlink message transfers between airborne aircraft and ground-based data link processors.

The Mode S system provides improved accuracy, eliminates synchronous interference or garble, provides an expandable architecture, and provides evolution of new technology with no performance degradation. The limitations of the existing ATCRBS operations are virtually eliminated while maintaining interoperability with ATCRBS transponders. This supports an extended transition to the new Mode S technology.

Mode S performance including monopulse positional accuracy, selective addressing, inter-netting capability and data link supports AAS implementation. Mode S provides accurate aircraft tracking and positive identification, which are critical to maintaining spatial separation and performing conflict prediction and resolution. Additionally, the AERA-1 and AERA-2 functions require the high-integrity positional data characteristic of Mode S.

Mode S provides a cost-effective data link service for ground-air-ground communication, requiring no additional airborne transmitting or receiving equipment beyond the Mode S transponder. This capability can serve most of the aircraft operations over the CONUS. Other data link services will be used for oceanic operations. Mode S will provide interoperability with other data link services conforming to the OSI standard via ATN.

Mode S data link will provide weather and flight information services, flight safety services, automated terminal information services, initial connection services, and AERA ATC connection mode services. Other data link services have been proposed such as traffic information service and hazardous weather graphics; route-oriented weather; and downlink of PIREPs, winds and temperature aloft, and trajectory information. Analyses will be performed to determine which of these services should be implemented.

Mode S sensors will be available in the near term. These sensors are currently in production testing and will become operational in 1993. An initial acquisition will result in deployment of Mode S sensors at 133 facilities. The FAA is performing studies to determine if additional sensors are required for NAS.

8.0 Glossary of Acronyms

AAS	Advanced Automation System
ACCC	Area Control Computer Complex
ACF	Area Control Facility
ADLP	Airborne Data Link Processor
AERA	automated en route air traffic control
AIRMET	airman's meteorological information
ARTCC	Air Route Traffic Control Center
ARTS	Automated Radar Terminal System
ASE	FAA System Engineering
ASM	FAA Systems Maintenance
ATC	air traffic control
ATCBI	Air Traffic Control Beacon Interrogator
ATCRBS	Air Traffic Control Radar Beacon System
ATIS	Automated Terminal Information Service
ATN	Aeronautical Telecommunications Network
BPS	bits per second
CWA	center weather advisories
CIP	Capital Investment Plan
CONUS	Continental United States
D-ELM	downlink extended length messages
DB	decibel
DLP	Data Link Processor
FAA	Federal Aviation Administration
FD	winds and temperatures aloft forecast
FT	terminal forecast
GDLP	ground data link processor
ICAO	International Civil Aviation Organization
IFR	instrument flight rules
MIT	Massachusetts Institute of Technology
Mode 2	ATCRBS Mode 2
Mode A	ATCRBS Mode A
Mode C	ATCRBS Mode C
Mode S	Mode Select Beacon System
MOPS	Minimum Operational Performance Standard
MTBF	mean time between failure
NAS	National Airspace System
NAWAU	National Aviation Weather Advisory Unit
NCP	NAS Change Proposal
NMI	nautical miles
NOTAM	notice to airmen
OSI	Open Systems Interface
PIREP	pilot reports
PPS	pulses per second
PRF	pulse repetition frequency
RMS	root-mean-square
RTCA	RTCA, Inc.
SA	surface observation

SARP	standards and recommended procedures
SEIC	System Engineering and Integration Contractor
SD	radar summary
SIGMET	significant meteorological information
SLS	sidelobe suppression
SSR	Secondary Surveillance Radar
TCAS	Traffic Alert and Collision Avoidance System
TCCC	Terminal Control Computer Complex
TIS	Traffic Information Service
TOC	transfer of communications
U-ELM	uplink extended length messages
UA	pilot reports
VFR	visual flight rules
VHF	Very High Frequency

9.0 REFERENCES

1. "Architecture Study", Martin Marietta, (DRAFT February 1991).
2. Mode S Project Office, working paper, "Mode S Parallel Runways Monitor" (4 December 1990).
3. V.A. Orlando, "Comparison of Aeronautical Data Links", SSR Improvements and Collision Avoidance Systems Panel, SSR Mode S System Working Group-1, SICASP/WG-1, WP/1/264 (16 August 1990).
4. H.L. Crane, P.N. MacDonald, "Validation of Mode S Capacity Requirements", Working Paper, WP89W00366, MITRE Corporation, (March 90).0
5. "Facility/Service Performance Report", FAA, Report No. SM-90-002, (December 1989)
6. J.L. Baker, V.A. Orlando, W.B. Link, and W.G. Collins, "Mode S System Design and Architecture", Proceedings of the IEEE, vol. 77, no. 11 (November 1989).
7. "Specification, Mode Select Beacon System (Mode S) Sensor", FAA-E-2716, March 24, 1983, incl. Chg. 24, (October 10, 1989).
8. V.A. Orlando, "Mode S Beacon System: A Functional Overview", Project Report ATC-150, MIT Lincoln Laboratory (29 August 1989), DOT/FAA/PM-89/7.
9. V.A. Orlando, "Mode S Capacity" SSR Improvements and Collision Avoidance Systems Panel, SSR Mode S Systems Working Group - 3, SICASP/WG-3, WP/3/ (30 March 1988).
10. V.A. Orlando, P.R. Drouilhet "Mode S Beacon System: Functional Description", Project Report ATC-42D, MIT Lincoln Laboratory (29 August 1986), DOT/FAA/PM-86/19.
11. W.C. Arthur, J.P. Fernow, N.J. Taber, "Functional Description of AERA 2, Automated Problem Resolution, Volume I, Problem Management", MTR-85W223, Mitre Corporation (January 1986).

12. J.P. Fernow, I. Frolow, D.A. Pool, C.A. Shively, N.J. Taber, G.R. Walker, J.F. Weidner, "Functional Description of AERA 2, Automated Problem Resolution, Volume II, Aircraft Conflicts", MTR-85W223, Mitre Corporation (January 1986).
13. D.F. Dubofsky, D.A. Pool, G.R. Walker, "Functional Description of AERA 2, Automated Problem Resolution, Volume III, Airspace Conflicts", MTR-85W223, Mitre Corporation (January 1986).
14. D.F. Dubofsky, J.D. Reiersen, "Functional Description of AERA 2, Automated Problem Resolution, Volume IV, Flow Restriction Violations", MTR-85W223, Mitre Corporation (January 1986).
15. "Key Decision Memorandum (Key Decision #4) for Mode S Surveillance and Communication System", U.S. Department of Transportation (7 March 1983).
16. "Secondary Surveillance Radar, Mode S, Advisory Circular", International Civil Aviation Organization, ICAO Circular 174-AN/110 (1983).
17. "Minimum Operational Performance Standards for Air Traffic Control Beacon System/Mode Select (ATCRBS/Mode S) Airborne Equipment", RTCA/DO-181A (SC-142) (January 1992).
18. "Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System (TCAS) Airborne Equipment", RTCA/DO-185 (SC-147) (September 1983).
19. "Proceedings of the 1982 RTCA Assembly", Radio Technical Commission for Aeronautics, AS-320 (17-19 November 1982).
20. W.I. Wells, "Verification of DABS Sensor Surveillance Performance (ATCRBS Mode) at Typical ASR Sites Throughout CONUS", Project Report, Discrete Address Beacon System, ATC-79, MIT Lincoln Laboratory (20 December 1977), FAA-RD-77-113.
21. Federal Aviation Administration, "Aeronautical Data Link Design Guidelines", DOT/FAA/SA-90-1, 2/26/91 DRAFT.

22. Kirkman, D., Signore, T. , Colliver, F., "Aviation Communications", The Mitre Corporation, MP-89W00017, May 1989.
23. Sutcliffe, W., et. al., "AERA 2 System Level Specification", The Mitre Corporation, MTR-85W00221, August 1991.
24. International Standards, Recommended Practices and Procedures for Air Navigational Services Aeronautical Telecommunications Annex 10 to the Convention on International Civil Aviation.
25. Mode S Data Link Capacity, Vincent Orlando, ATC project memorandum #42PM-Mode S-0026